Influence of angularity of coarse fraction grains on internal erosion process

Didier MAROT, Fateh BENDAHMANE, Hong Hai NGUYEN
Background

Two types of internal erosion process in uncracked soils: **backward erosion** and **suffusion**

Diffuse redistribution of **fine particles** within the soil.

Slight changes of grain size distribution and the **hydraulic conductivity** can evolve notably (Lafleur, 1999; Bendahmane et al. 2008; Marot et al. 2009)

Result from **seepage flow** in the soil pores ➔ great influence of **geometry of the interstitial vaccums**

Granular assembly which depends on:

- **grain size distribution** (Wan and Fell, 2008; Li and Fannin, 2008, etc...)
- **mechanical loading conditions** (Skempton and Brogan, 1994; Moffat and Fannin 2011)
- **grain shape**
  
  Average pore diameter as a function of shape coefficient (Kovacs, 1981)
Experimental devices

Triaxial erodimeter for **suffusion tests**

- Small quantity of eroded particles

**Multichannel optical sensor**

- Measurement of fine particle concentration
- Distinction between fines and sand grains

[Marot et al. (2011), Canadian Geotechnical Journal]
Optical and mechanical methods used for characterization of grain angularity

- **Optical microscope** (max enlargement: 40) associated with digital camera
  - Picture analysis

  For each tested aggregate

  \[
  \text{Roundness} = - \frac{P^2}{4.\pi.A} \quad \text{Circularity} = \frac{1}{n} \sum_{i=1}^{n} \left( r_i - r_{\text{moy}} \right)^2
  \]

  P: perimeter; A: cross section; r_i: radius; r_{\text{moy}}: average radius

- **Direct shear box** with density index \(I_d\) near to 1
  - Internal friction angle

- **Angulometer**: standardized funnel, measurement of the gravitating flow duration \((E_{cm})\). Angularity index \(I_A\): ratio of flow duration of aggregate to flow duration of glass beads
Tested materials

Mixtures of 10% of kaolin and 90% of one of the following aggregates:

- Fontainebleau sand (F) \( (75\mu m-425\mu m, D_{50} = 207\mu m, \text{uniformity coefficient} = 1.33) \)
- Loire sand (L) \( (80\mu m-1\text{mm}, D_{50} = 440\mu m, \text{uniformity coefficient} = 3.13) \)
- Modified Loire sand (LM) composed of grains from L, grain size distribution of F
- Glass beads grain size distribution of F

![Graph showing grain size distribution](image)

Laser diffraction particle-size analyzer
Specimen preparation for suffusion tests

Preliminary forming of specimen by single layer semi-static compaction technique

Specimen placed on a 4mm pore opening grid → migration of all particles

Saturation phase with carbon dioxide, demineralized and deaerated water

Consolidation (100kPa) → dry density 17.5kN.m⁻³

Suffusion test under constant hydraulic gradient

<table>
<thead>
<tr>
<th>Loire sand</th>
<th>Circularity (μm²)</th>
<th>Roundness (.)</th>
<th>Diameter (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25.87</td>
<td>1.19</td>
<td>311</td>
</tr>
<tr>
<td></td>
<td>263.03</td>
<td>1.4</td>
<td>478</td>
</tr>
<tr>
<td></td>
<td>2 217.32</td>
<td>1.9</td>
<td>580</td>
</tr>
</tbody>
</table>

Circularity very sensitive

X 85
X 1.6
100 pictures for each aggregate

Glass bead | Fontainebleau (F) | Loire (L)

| Circularity ($\mu m^2$) | 3 (22) | 63 (52) | 178 (305) |
| Roundness (.) | 1.13 (0.06) | 1.39 (0.15) | 1.42 (0.19) |

| Internal friction angle ($^\circ$) | 30 | 37 | 44 |
| Flow duration $E_{cm}$ (s) | 17 | 22 | 23 |
| Index $I_A$ (-) | 1 | 1.29 | 1.35 |

⇒ Same relative classification
Glass beads: smallest values
Fontainebleau sand: intermediate
Loire sand: largest values
Suffusion test results

Specimen constituted by kaolin and glass beads ➔ instability during saturation phase

F and ML, **same grain size distribution**, same applied hydraulic gradient \(i=0.8\)

Clay concentration in effluent

➔ Effect of grain shape: increase of resistance by a factor of 5
ML: more important decrease of hydraulic conductivity

Decrease in hydraulic conductivity attributed to particle filtration

(Reddi et al., 2000; Bendahmane et al., 2008; Marot et al., 2009, 2011)

→ angularity seems to contribute to increase filtration process
Maximum clay concentration versus

1. Internal friction angle
2. Angularity index
3. Gravitating flow duration
4. Roundness
5. Circularity

Optical parameters no distinction between ML and L, great values of standard deviation ⇒ **Mechanical approach : preferred**
Thank you for your attention!

Contacts:

didier.marot@univ-nantes.fr
fateh.bendahmane@univ-nantes.fr
hong-hai.nguyen@univ-nantes.fr

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Suffusion test results

Mixture of 10% kaolin and 90% Fontainebleau sand

- \( i = 0.6 \)
  - No erosion
  - Hydraulic conductivity stays constant

- \( i = 2.5 \)
  - \( C_{\text{max}} = 0.55 \text{mg/g} \)
  - Hydraulic conductivity decreases from \( 10^{-5} \text{m/s} \) to \( 10^{-6} \text{m/s} \)
Suffusion test results

Mixture of 10% kaolin and 90% Loire sand

i=20
$C_{\text{max}} = 1.1 \text{ mg/g}$
Important decrease in only a few minutes

i=2.5
$C_{\text{max}} < 10^{-2}\text{mg/g}$
hydraulic conductivity decreases from $10^{-5}\text{m/s}$ to $10^{-6}\text{m/s}$